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PREFACE

In August 2003, during the NAFI/NFPA National Fire, Arson, and Explosion Investigation Training Program in Sarasota, Florida, a small group of dedicated fire investigation educators met at the NAFI international offices. Their purpose was to discuss and ultimately to set in motion a new concept in fire investigation education. This innovation became the International Symposia on Fire Investigation Science and Technology (ISFI).

That group consisted of Professor Ronald L. Hopkins, CFEI, CFPS, of Eastern Kentucky University's Fire and Safety Engineering Technology Program (now retired) and former Chairman of the International Society of Fire Service Instructors; Daniel L. Churchward, CFEI, then Chairman of the National Fire Protection Association's Technical Committee on Fire Investigations (1996 to 2008); Station Officer Michael G. Beasley, CFEI, senior fire investigator of the London (England) Fire Brigade; Attorney Stuart A. Sklar, CFEI, fire litigation attorney; Divisional Officer Patrick G. Cox, CFEI, MIFireE, ASAESI, Director of Fire Investigation Training at the British Fire Service College (now retired); Fire Investigator Kathryn Kennedy Smith, CFEI; Fire investigator Gregory E. Gorbett, CFEI, CFPS, MIFireE; the late Frank L. Florence, CFEI, Senior Fire Protection Specialist, National Fire Protection Association; and the late Patrick M. Kennedy, CFEI, CFPS, MIFireE, Chairman of the National Association of Fire Investigators.

These dedicated professionals became ISFI's organizing and peer review committee.

It is not mere coincidence that all of these original group participants are current or past members of the NFPA Technical Committees on Fire Investigations (NFPA 921) and/or Fire Investigator Professional Qualifications (NFPA 1033) and their respective Task Groups. Since 1985 the partnership between the NFPA and NAFI has been dedicated to and striving for the betterment of fire investigation, worldwide.

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INTRODUCTION

The International Symposium on Fire Investigation (ISFI) 2024 is the premier gathering of fire investigation professionals, showcasing cutting-edge research and technology in the field. Held biennially, ISFI was first presented at the British Fire Service College in 2004, and has since been held in prestigious locations such as the University of Cincinnati and the University of Maryland.

This year, ISFI will take place in Orlando, Florida, marking its tenth presentation. Organized by the National Association of Fire Investigators and Investigations Institute, ISFI aims to facilitate the exchange of knowledge and ideas among fire investigation practitioners, educators, researchers, and attorneys from around the world. With a focus on promoting the latest advancements in fire investigation science and technology, ISFI has become the premier event for fire investigation professionals seeking to stay well versed of the latest developments in the field.

Kathryn C. Smith, CFEI
Chairman, National Association of Fire Investigators, International
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DEVELOPMENT OF A SYSTEMATIC METHODOLOGY FOR RECONSTRUCTING THE FIRE SCENE BY USING THE ELECTRICAL SYSTEM

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ABSTRACT

Forensic Scientist, Engineers, and Fire Investigators (Fire Investigation Practitioners), often working together as a team are commonly tasked with determining both the origin and the cause of fire. The internationally recognized, National Fire Protection Association (NFPA) 921: "Guide for Fire and Explosion Investigations" currently outlines three methods of data collection to assist in fire origin determination. These are (1) witness information and / or electronic data, (2) fire patterns and (3) fire dynamics[1]. The correct application of any fire origin determination method is incumbent on the knowledge, skill, education, training and experience of the fire investigator. Currently, the most commonly published method of utilizing the electrical system for origin determination is called arc mapping, although more correctly identified as arc surveying. According to NFPA 921, an arc survey is based on the fire investigator's ability to identify and document a fire pattern derived from the identification of electrical generated arc sites on wiring that may be used to aid in determining the area of fire origin and/or spread[1]. Research was conducted to determine whether fire investigators could reliably perform the arc survey methodology and explore any knowledge gaps that may exist[2].

The first objective of this research was to explore the ability of fire investigation practitioners to correctly identify different types of electrical artifacts and the impact that a short (1hr) custom training intervention had on this capability. The second objective was to determine the ability fire investigation practitioners to mobilize existing electrical knowledge to assist in origin and cause determinations at a scene and the impact of training on this skill development. To achieve these objectives, 65 full-scale, live burn cell experiments and 121 scaled experiments using a newly designed experimental test apparatus were conducted utilizing both United Kingdom and North American electrical cabling. The ability of the scaled experiments to generate the same morphological artifacts as a full-scale fire was validated and a subset of the generated artifacts from both the full-scale fires and scaled experiments were used as the test set for surveyed fire investigation practitioners[2].

Qualitative and quantitative data was collected by surveying 912 respondents within the fire investigation community across four test conditions. The resultant data demonstrated that a short electrical fire training session improved fire investigators abilities to correctly distinguish between arc melt sites and fire melt sites by over 30%. Moreover, the abilities of fire investigators, once formally and effectively trained (40hr) to correctly implement their electrical knowledge for fire origin determinations additionally increased by over 30%[2].

BACKGROUND

Globally, fire investigators are from both public (fire and rescue, law enforcement, publicly funded forensic science providers, academic and other public bodies) and the private sector fire and explosion investigation organizations. In general, fire investigators come from either a scientific or an engineering background. These disciplinary areas have differences in the underlying approaches that they may have to the investigation of a fire. Science can be defined as a means of developing systemized knowledge while engineering can be defined as the application of science to specific tasks[3]. For example, electrical scientists or physicists explore and research the fundamental laws governing electricity whereas

power electrical engineers define boundaries based on science & engineering to design and build electrical generation and distribution systems.

The scientific method can be considered as a principle of inquiry that forms a basis for legitimate scientific and engineering research, including a systematic approach for fire investigation[1]. The hypothesis is developed early in the methodology and the scientific methodology is based on a rigorous truth test.

In contrast the forensic engineering methodology begins with an occurrence of an event; the methodology is based on cumulative logic.

FIRE INVESTIGATORS APPROACH TO FIRE INVESTIGATION

In 1992, the newly released NFPA 921, "Guide for Fire and Explosion Investigations" adopted the scientific method as a systematic approach to fire investigation[4]. In 1998, NFPA adapted the scientific method to better fit the fire investigation methodology[5]. The latest edition of NFPA 921 (2024 edition)[1], presents a further adaptation of the scientific method for fire investigation to create a series of well-defined steps[1].

This adapted NFPA 921 fire investigation methodology appears to combine both the scientific and forensic engineering methods to suit fire investigation methodology where the hypothesis is not developed until after data is collected.

Defining the problem, collecting data and analyzing the data are self-evident within the NFPA 921 methodology. The fire investigator is directed to utilize inductive reasoning for developing a hypothesis. Inductive reasoning (as defined by NFPA 921) is the process by which hypotheses are developed based upon observable or known facts and the training, experience, knowledge, skill and expertise of the observer. When testing a hypothesis, the fire investigator may use deductive reasoning, the process by which conclusions are drawn by logical inference from given premises. The final hypothesis emerges as a result of the process and the fire investigator only forms a valid or reliable conclusion once the hypothesis stands the test of careful and serious challenge[1]. The selection of the final hypothesis should provide an acceptable or prescribed level of confidence or certainty.

POTENTIAL BIASES IN FIRE INVESTIGATION AND THE IMPORTANCE OF TRAINING

Fire investigation, generally considered to be an activity which involves pattern matching, can be subject to cognitive and other biases[6]. Historically, the pre-1990 fire investigator had minimal subject matter training or research background[7] and generally based their opinions on previous observations, experience and expert knowledge often reinforced by their mentors and/or peers. As the profession has matured, scientifically valid research has dispelled many unfounded theories and biases, resulting in the emergence of rich scientific and engineering literature.

While the underlying problems of expectation and/or confirmation bias are well known phenomena within scientific or engineering research, fire investigators, like many forensic science practitioners, have become more aware of the potential impact of cognitive and confirmation bias in recent years. Research has highlighted the importance of human factors and bias in expert assessment[8] and that managing human factors through effective training and education can enhance quality and technical competence[9].

Fire investigators are expected to have a wide range of knowledge and skill base generally derived from a combination of training and performance qualifications. Professional qualifications are developed against clear and concise requirements that can be used to determine that an individual possesses the knowledge, skills and experience to perform as a competent fire investigation practitioner. In the United Kingdom, the

Code of Practice for Investigators of Fires and Explosions for the Justice Systems in the UK provides guidance to organizations and individuals engaged in the investigation of fires[10]. Additionally, the Royal Society, Fire Investigation Primer for the Courts provides additional guidance[11]. In North America, NFPA 1033 Standard for Professional Qualifications for the Fire Investigator is the governing standard[12].

Fire investigators are expected to maintain their competence by attending formal education courses, workshops, and seminars[12]. Workshops and seminars, while useful for continuing education, should not replace formal, post-secondary subject matter education. Fire Investigation certification programs from both the International Association of Fire Investigators (IAAI) and National Association of Fire Investigators (NAFI) and International Organization Standardization (ISO) standards aid in setting a threshold for professional qualification(s). In the United Kingdom, fire investigators are expected to demonstrate the essential knowledge and skills equivalent to those listed in the National Occupational Standards for Fire Investigators as listed in the United Kingdom Code of Practice document[10].

Presently, fire investigators apply fire investigation methodologies that are derived and developed from a focus of fire science, however in many cases fire investigators find electrical theory and the application of this in a meaningful way to fire scene investigation, a considerable challenge.

THE ROLE OF THE ELECTRICAL SYSTEM IN FIRE INVESTIGATION

The fundamental laws of physics form the basis of all matters associated with fire and electricity. From these laws, units of measure are derived to underpin and combine scientific research within both fire and electrical investigations.

Electricity has been harnessed and safely used within structures for nearly two hundred years. Initially, in the late 1800's a single residential structure may have had a single electrical circuit that provided electrical current to illuminate a single light bulb. However today, electricity completely encompasses every facet of our lives. Electrical equipment and wiring are installed throughout modern structures to provide light, heat and/or motion.

Electrical circuits are installed throughout a structure, which may be concealed. However, in many instances the electrical circuits, equipment, luminaires, appliances and fittings are surface mounted or otherwise exposed.

Trained, qualified and competent electrical practitioners understand that each electrical system has both independent and dependent electrical variables; meaning that no two electrical installations nor systems are the same. Fire investigators must have knowledge of electrical theory and systems as well as understand the hazards associated with each electrical system under investigation[10,12].

The earliest literature related to the idea of electrical surveys or otherwise investigating the electrical system role in fire investigation dates back to a 1955 fire investigation manual titled "Techniques of Arson Investigation" authored by Straeter and Crawford[13]. The authors suggested fire investigation purposes.

"The amount of destruction of insulation on electric wires can reveal a clear pattern for the area of intense heat. Electric shorts have their physical effects. Investigate to be sure whether the short caused the fire or the fire caused the short. The exact locations of wire damage, of char, and of the other indications may well be compared to answer this question." Additionally added that the "Sequence of shorted electric circuits. The appliances that were stopped by electrical failure may indicate the path of the fire to some degree, especially in a larger building in which there are many circuits, and they were put out one at a time. The times at which the clocks stopped could tell which circuits were included first in the fire's path."

Paul L. Kirk's "Fire Investigation" in 1969[14] was the first widely recognized publication related to fire investigation. The formation of an NFPA technical committee on the investigation of fires of electrical origin in the 1970s led to the developed NFPA 907M, a manual on the investigation of fire of electrical origins in 1983[15]. NFPA 907M was later updated as the 1988 edition under the title of "Manual for the determination of Electrical Fire Causes"[16] Ettling researched the different damage types observed between internal and external heating of electrical cabling[17-20]. Beland also wrote numerous papers related to electrical equipment and wiring and its role in fire investigation[21-27].

In 1992, NFPA issued the first edition of the Guide for Fire and Explosion Investigations (NFPA 921)[4]. NFPA 921 has been revised and updated approximately every three years since the first edition[1,4,28-32]. Although NFPA 921 is titled as a "Guide", the fire investigation community within North America has generally accepted it as a standard for the practice of fire investigation. The NFPA 921 document has also been internationally accepted or otherwise generally referenced for global fire investigation purposes.

Several texts related to fire investigation have been authored for the fire investigation community. Noted texts and authors include, in part; Introduction to Fire Dynamics, authored by Drysdale[35], Fire Investigation, edited by Nic Daeid[36], Kirks Fire Investigation, authored by DeHaan[14], and Principles of Fire Behavior, authored by Quintiere[37].

The measurable, quantifiable and predictable nature of electricity may assist researchers to develop systematic reliable methodologies for the international fire investigation community. This suggests that a scientifically robust focus for fire and fire investigation research should include both qualitative and quantitative investigations of electricity and its impact on materials, fire and fire investigation methodologies.

Examination of post-fire damage patterns to electrical wiring and equipment within buildings may provide fire investigators with meaningful engineering and fire investigation data that identifies the location of a fire's area of origin and potentially the determination of its cause. The various versions of NFPA 921: "Guide for Fire and Explosion Investigations"[1,4,5,28-34] describes the origin of a fire as one of the most important hypotheses that a forensic investigator develops and tests during their investigation. It further outlines the methodology of coordinating data gathered from one or more of the three recognized origin determination methods. The three methods currently recognized are witness information and/or electronic data, fire patterns, and fire dynamics[1]. The increased availability of electronic data provides additional unbiased data for the investigator to consider during the course of the investigation.

Data collected during the fire origin determination phase becomes the foundation of the fire investigation. This in turn may lead to further understanding of the fire development and determination of the area of origin, sequence of events, point of origin and cause. Arc mapping, a systematic investigation of the electrical conductors within a fire scene for evidence of electrical faulting either as a cause or consequence of the impingement of fire on those conductors, has the potential to contribute to this information. Arc mapping, also referred to as an arc survey, has historically been accepted within the fire investigation community as a reliable fire origin determination methodology[28-30, 32]. Historically, some forensic investigators have tended to attempt to answer a cause of fire question before answering the critical area of origin of the fire in question and the reversal of this frame of thinking is required so that the effectiveness of utilizing the electrical system as an investigative tool for origin determination becomes more sensibly applicable.

Prior to the adoption of the 'arc mapping' terminology by NFPA 921, engineers and electricians better described the methodology of determining a fire's origin by use of the electrical system as electrical power system analysis or Arc Fault Circuit Analysis (AFCA). AFCA was originally based on classical electrical power system fault or short circuit analysis and associated calculations[38] and is a system that has

been rigorously tested, peer reviewed and published within the electrical industry[39-42]. The methodology was further developed and tested by electrical engineers and electricians for the fire investigation community. In 1983, consulting engineers, Deplace and Vos theorized that most short circuits that occurred during a fire were the result of a fire rather than the fire cause[43]. They further suggested that the systematic mapping of the locations of short circuits could provide assistance in locating the area of origin, establishing the corner stone for the fire origin methodology known as arc mapping or arc fault circuit analysis.

The desire to reliably develop a methodology to distinguish between arcing events that cause a fire versus arcing events that occur as a result of a fire attack on energised conductors began in the 1970's. Numerous researchers conducted experiments attempting to develop a reliable methodology to examine post-fire electrical conductors and distinguish between "cause" and "victim" arc damage. Anderson developed the Auger methodology where he opined that by conducting metallurgical analysis of the arc melt damage, the question as to whether the arc damage generated was the cause or victim of a fire could be determined[44-46]. The Auger method was subsequently challenged and determined as unreliable[47]. It is currently accepted within the fire investigation community that a reliable methodology has yet to be developed to distinguish the difference between fire causal and victim arc sites.

Recent publications by Babrauskas suggested that the electrical system response and subsequent physical evidence generated during the course of a fire were random events and as such, inferences drawn from physical evidence such as arc melt sites through the use of arc mapping may not necessarily contribute to the origin and cause determination[48,49]. This conclusion has been disputed by others, and the evidence base underpinning these suggestions brought into question particularly because some of the evidence used by Babrauskas may have been generalized and taken out of the context within which it was generated[50]. Babrauskas also concluded, in part, that he could not find much promise with any of the methods that were proposed for distinguishing between cause and victim beads and that reliable distinctions between the two were yet to be discovered[47]. The advancement of research to enable the reliable interpretation of electrical artifacts as corroborating evidence for fire origin and cause is of importance to provide clarity to the field. Associating this with appropriate training to develop investigators skills in the identification of electrical arcing and evaluating that training for its effectiveness is also highly desirable.

Outside of the United Kingdom (UK), the majority of the published literature related to arc mapping (arc survey) has been theoretical in nature. Therefore, the aims and objectives of this research was to determine, whether the electrical distribution system could assist the fire investigator in a practical sense in reconstructing the fire scene and reliably determining the area of origin of the fire based on the electrical system.

GENERATION OF DATA SETS – EXPERIMENTAL DESIGN AND METHOD DEVELOPMENT.

Electrical experiments were performed at three separate locations within North America. The purpose of the experiments was to quantitatively determine how energised and non-energised electrical copper cabling responded when impacted by fire conditions. Experiments for each series were repeated to ensure scientifically reliable data. The experiments conducted during this research reflect the electrical conditions that existed at the time of the experiments. Additional experiments may be required for different or varying electrical circuit configurations and installations[2]. The series of experiments are further described within journal articles published by the National Academy of Forensic Engineers (NAFE)[51,52].

Artifacts generated through Carey's research[53] were also provided for incorporation into the overall project data set. These samples were generated using UK cables installed within full scale compartments under real fire conditions. The inclusion of these samples enabled a direct comparison between the UK and North American (US) samples to be made in terms of characterization of damage. Artifacts from both

the US and UK (Carey's) datasets were incorporated into the practitioner surveys which were undertaken by participants from both the US and UK, and this enabled differences between UK/US practitioner responses to be made[2].

A total of 721 artifacts (this study and Carey's samples[53]) were examined and categorized into arc melting, fire melting, fire impinged, mechanical damage, non-melted artifacts. The generated samples included 476 artifacts of electrical arc melting, 102 artifacts of fire melted electrical conductors and 143 artifacts of fire impinged, mechanical damaged or non-melted (NM) electrical conductors.[2,51,52,53]

Experiments supported commonly known and generally accepted electrical fault analysis procedures can apply to fire investigation. Whereby an electrical analysis of a one-line diagram in conjunction with arc fault analysis can define a region of interest or area of origin.

THE IDENTIFICATION OF CONDUCTOR DAMAGE: HUMAN FACTOR ANALYSIS

Three surveys were designed and developed to explore the potential knowledge gap in regard that fire investigators potentially lack the requisite electrical training that may directly impact their abilities while performing fire investigations. Demographic and examination data was collected and compiled using surveys and analytic software.

The surveys were administered in person and required participants to answer a series of qualitative and quantitative questions related to their education, training and experience as well as their observations of a set of post-fire damaged electrical conductor samples created through the practical experiments.

The participants of the various surveys were drawn from delegates attending fire investigation conferences in both the United Kingdom (UK) and United States of America (USA). In total 912 people participated across the three surveys.

The fire investigation conferences where the survey was undertaken within the United Kingdom and United states were well attended. With an overall delegate attendance estimate of 2500 attendees. Approximately 37% of the attendees completed the survey.

The most common occupation of the participants were fire investigators (57%), followed by fire fighters (19%).

Among all the practitioners who took part in the surveys, half had 10 years or less experience as fire investigators. 73% of practitioners investigated 50 fires or less across a year and 27% investigated between 51 and over 100 fires per year.

Of those practitioners who took survey one, the majority (59%) had less than 4 hours (half a day) of previous training in electrical fire investigation, 19.5% had 8 hours (1 day) and only 21% had more than one day's training per year. Similar lack of training trends were observed across the other survey participants demonstrating a potential knowledge gap that may impact their ability to conduct electrical investigations.

Survey one participants were additionally asked their view on the reliability of arc mapping (arc survey), with 91.28% responding that they considered arc mapping to be a reliable method for fire origin determination, notwithstanding this, only 26.15% of the participants said that they applied the arc mapping methodology on a regular basis.

The results of each of the surveys are presented in order and discussed in the following sections.

SURVEY ONE – BASELINE KNOWLEDGE TEST.

The first survey was developed as a baseline knowledge test. The purpose of the survey was to determine whether fire investigation (and other) practitioners were able to reliably determine post-fire damage on electrical conductors by observation only but without any specific custom training provision prior to taking the survey. This acted as a baseline knowledge test.

Overall analysis of the first survey revealed that, on average, 54% of participants were able to correctly distinguish the differences between arc melting (AM), fire melting (FM), mechanical damage (MD) and non-damaged (ND) electrical conductors. These scores were considerably higher for fire investigators (60%) and engineers (72%) respectively.

SURVEY TWO – BASELINE KNOWLEDGE TESTS FOLLOWED BY ADDITIONAL TRAINING AND RETESTING.

Based on the results of survey one (the baseline knowledge test), a modified second survey was developed and administered. The modification of the survey included questions relating to additional training which the participants undertook which related to the recording and review of damage size, porosity X-ray imagery and grey scale features of artifacts under test.

The primary purpose of the second survey was to determine whether a correlation existed between the participant's initial examination scores examining the cause of damage observed on post-fire damaged electrical conductors and their examination scores following a one-hour training session.

The survey was in two parts and participants completed both parts. Firstly, the participants reviewed photographs of the artifacts and then answered questions regarding the identification of the damage to the conductors (survey 2A). Following the completion of the first part of the survey the participants undertook a one-hour training session which highlighted observable features of damage sites and information related to X-ray radiographic observational differences between the different types of damage. They then completed survey 2B.

OUTCOMES OF SURVEY 1 AND SURVEY 2 (2A AND 2B).

When comparing the results of survey 1 and survey 2A in terms of the average percentage of correct answers for each damage type (arc melting, fire melting and mechanical melting), the participants scored best (in terms of correctly identifying the type of damage) when that damage was mechanical in nature.

The results reveal a difference of approximately 10 percent decrease in scores between survey 1 (57.7% (the background study using the artifacts)) and survey 2A (47.1% (reviewing images of the artifacts)), when identifying arc and fire melting. This may be due to the way in which the artifacts were presented with better results obtained when the physical artifact was examined. The data from survey 2B (81.1%) clearly illustrates the impact of the training provided, where in the case of both arc melting and fire melting the correct assignation rose by 44% and 31% respectively.

The specific percentages of correct survey answers for survey 1 and 2 again support the assertion that the use of training has greatly increased the abilities of the participants to correctly identify the damage on the conductors used in the study.

A Chi-Squared test was used to investigate the impact of the training on the outcomes. The test results confirmed the assertion that the training administered to participants between Survey 2A to 2B had a significant difference on the participants abilities to correctly identify the type of damage on the conductors examined.[2]

SURVEY THREE – BASELINE KNOWLEDGE TESTS OF THE IMPLEMENTATION OF ELECTRICAL SURVEYS AND ARCING FAULT EVALUATIONS IN ORIGIN DETERMINATION.

A third survey was developed to determine whether an electrical knowledge gap existed within the fire investigation community when applying knowledge of the electrical distribution system during the course of fire origin determinations. This goes beyond simply the identification of different types of electrical damage and seeks to explore whether the location of electrical artifacts within a scene can inform origin determination.

The primary purpose of the third survey was to determine whether participants were able to independently apply electrical knowledge, data, electrical survey and arcing fault evaluations when making a determination of an area of fire origin based on the electrical system.

The outcome of the survey of practitioners revealed, in part, an electrical knowledge gap where fire investigators lack fundamental knowledge and skill related to electrical theory, installations and damage. Fire investigators currently rely upon visual electrical patterns or subjective electrical data when making assessments related to fire origin and cause determinations. This knowledge gap is further underpinned by incorrect terminology and definitions within NFPA 921[1]. Whereas NFPA 921 incorrectly defines an arc site as a fire pattern derived from the effects of fire[1].

The electrical investigation at a fire scene should begin with an electrical survey followed by an arcing fault evaluation.

Practitioners should be able to utilize the electrical system to reconstruct the fire scene through a systematic approach to examining, collecting and analyzing electrical data. The arc survey methodology should fundamentally consist of identifying and documenting how the electrical distribution system and wiring were installed and operated and how the electrical system responded to the fire and locating area(s) where the electrical faults occurred. To successfully undertake an arc survey, the fire investigation practitioner should be, in part, additionally, skilled, trained, qualified and competent in the areas of electrical safety and installation practices related to the electrical system (residential, commercial, industrial, agricultural and transportation vehicles) under investigation. Therefore, a 40-hour electrical training course was developed[2].

Participants received instruction in two partes that provided a total of 40 hours of training. Part one of the 40-hour training course content consisted of 24 hours of both classroom instruction and practical exercise training. Course topics included, in part, fundamentals of electricity, electrical power generation, transformers, residential (domestic) electrical systems, current limiting devices, electrical circuits, electrical circuit control, appliances, and practical electrical training board exercises. Each candidate had to successfully pass oral, written and practical examinations to participate in part two training.

Part-two of the 40-hour training course content consisted of 16-hours of both classroom instruction and practical exercise training. Course topics included, in part, electrical system surveys, arc fault circuit analysis, arc mapping, arc surveys, fundamentals of metallurgy, identification of electrical damage sites, electrical distribution examinations, advanced electrical system analysis, and advanced practical exercises. Each candidate had to successfully pass oral, written and practical examinations to complete the course.

CONCLUSIONS

The majority of the published literature related to arc mapping (arc survey) has been theoretical in nature. Therefore, the aims and objectives of this research was to determine, whether the electrical

distribution system could assist the fire investigator in a practical sense in reconstructing the fire scene and reliably determining the area of origin of the fire based on the electrical system.

The purpose of the research was to develop a systematic methodology for reconstructing the fire scene by using the electrical system. A set of electrical samples and surveys were generated to assist in determining if a fire investigator electrical knowledge gap exists. Arc and fire melt samples under full-scale and scaled fire conditions were generated for this research. Samples were prepared so that a series of surveys could be undertaken to explore (a) the ability of fire investigators to correctly identify the artifacts and (b) to evaluate the efficacy of training methodologies in improving the ability to identify the artifacts and implement that knowledge in a scenario-based context. The dataset generated applies to practical fire investigation scenarios where cabling is uniformly exposed or otherwise surface installed as the generated samples mimic such scenarios. Currently, the most commonly published method for utilizing the electrical system for origin determination is arc mapping (arc survey).

Qualitative and quantitative data was collected by surveying 912 participants within the fire investigation community to assess, in part, their ability to correctly identify arc, melt and mechanical artifacts and use arc fault data in a scenario-based context. Survey one participants were provided with post-fire damaged electrical conductor samples for visual observation, without any additional data. The overall results revealed that respondents had a low probability of distinguishing the differences between arc melting and fire melting.

The ability to accurately identify conductor damage is a key step in any electrical evaluation, including the arc mapping methodology. The inability of participants to correctly identify damage on post-fire damaged electrical conductors indicated a knowledge gap within the fire investigation profession.

Survey two participants were provided with an additional one-hour training session on how to visibly identify and distinguish the difference between arc melted and fire melted post-fire damaged electrical conductors including through the interpretation of X-Ray radiographs of the artifacts. Their ability to correctly identify the artifacts observed on post-fire damaged conductors increased from a mean examination score of 45.6% to a mean score of 78.6% as a result of the training. Statistical evaluation further correlated that additional training had a significant positive effect in the participants abilities to correctly attribute the damage observed.

A third survey of participants identified an additional knowledge gap affecting participants' ability to accurately apply electrical conductor damage data to electrical distribution-based scenarios for fire origin determination. The ability of the fire investigation practitioner to correctly identify the area of origin and fire spread without training was 51.6%.

The preliminary results of survey three demonstrate that the general lack of fire investigator understanding of electrical systems and how it can be utilized within the context of a fire investigation. This conclusion is further supported by the work of Forte, Frucci and Keener[54].

A 40-hour electrical training course was developed to address the skills gap and participants were tested, in part, by using survey three before the course. A practical exercise version of survey three was administered, in part, of the course final examinations. That resulted in participant success rate for the correct determinations of both area of origin and fire spread based on the electrical system rose to 95% after taking the course[2].

Therefore, continued development of international, post-secondary, single phase electrical training programs for the fire investigation profession should be compulsory. Thereby enabling fire investigation practitioners to implement their training and demonstrate competency in the identification of arc and fire

melts as well as determine their role in origin and cause determinations. Additional three-phase, commercial and industrial training should be further evaluated.

ABOUT THE AUTHORS

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Mark is a licensed Master Electrician, and Professional Electrical Engineer who has been involved in Forensic Engineering since 1990. Mark conducted his doctoral research at the Leverhulme Research Centre for Forensic Science, School of Science and Engineering located at the University of Dundee, United Kingdom. He also has a Bachelor of Electrical Engineering (B.E.E.) degree from the University of Minnesota. He is also a veteran of the United States Navy, where he served as an Electronic Warfare Specialist on board the U.S.S. Briscoe DD977. While in the Navy, Mark served in regions such as South America, Europe, and Mediterranean Countries. Mark has taught numerous electrical courses for international, U.S. federal, state, local, and private organizations, including the Bureau of Alcohol, Tobacco and Firearms Advanced Fire Investigation program located at the Federal Law Enforcement Training Center – Brunswick, Georgia. Mark has been involved with the evaluation and analysis of electrical distribution, controls and equipment failure events that include, in part, fire, explosions, personal injury and equipment damage. Mark's practical experience and hands-on approach to investigations has qualified him as an electrical expert in both U.S. federal and state courts.

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Professor Niamh Nic Daeid is Director of the award winning Leverhulme Research Centre for Forensic Science (LRCFS) the 10-year mission is to provide a robust underpinning for the scientific evidence presented in our Courts. She is a Chartered Chemist and an authorised Forensic Chemist with specialisms including fire investigation, clandestine drug chemistry and explosives. Niamh undertakes forensic casework, primarily in fire scene investigation and has appeared as an expert witness for the Courts. She has chaired the European Network of Forensic Science Institutes (ENFSI) fire and explosion Investigation working group, the INTERPOL forensic science managers symposium and was deputy chair of the Scientific Advisory Board of the International Criminal Court. She is a Fellow of the Royal Society of Edinburgh and holds fellowships with the Royal Society of Chemistry, the Institute of Chemistry of Ireland, the Royal Statistical Society, the UK Association of Fire Investigators and the Chartered Society of Forensic Science. She led the teams that created the Code of Practice for Investigators of Fires and Explosions for the Justice Systems in the UK and the development of the Fire investigation judicial primer. Niamh has received many awards for her work including the Stephen Fry Award for public engagement, the ENFSI Distinguished Forensic Scientist award and the Peter Ganci award for services to fire investigation.

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